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(54) **High-voltage bushing**

(57) The subject of the invention is a high-voltage bushing applicable in electric power engineering. The high-voltage bushing comprises a condenser core (1) and electrically conducting field-grading layers (3) which are arranged coaxially around the central conductor (2) and are embedded in insulating material (4) of the condenser core (1). An electric connection (6) is provided to at least one layer (3a) of the field-grading layers (3) by means of a current-collecting member (5). The layer (3a) is made in form of thin metal film deposited on an electrically insulating substrate layer or in form of a percolating network of conductive particles suspended in a layer of electrically insulating material, and the current-collecting member (5) is positioned on the surface of the layer (3a) and it covers a part of the surface area of the layer (3a) and has the surface resistivity many times smaller than the surface resistivity of the layer (3a). The current-collecting member (5) is shaped so that the length of the contour line of its circumference (L) is greater than the length of the shorter side of the layer (3a).

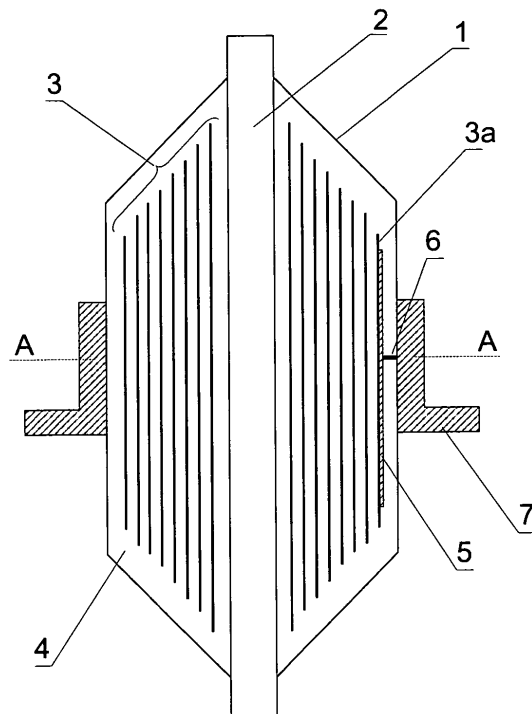


Fig. 1

Description

[0001] The subject of the invention is a high-voltage bushing applicable in electric power engineering.

[0002] Bushings are devices used to lead a conductor under voltage through an opening in a wall or equipment at ground (earth) potential. A typical condenser bushing for medium- or high-voltage applications, that is, from 24kV to 800kV and above, comprises a condenser core with a number of concentric electrically conducting field-grading layers of cylindrical shape arranged around the central conductor so as to form a capacitive divider uniformly distributing the voltage among the field-grading layers. As a result, the electric field generated by the high voltage is also uniformly distributed, both inside the condenser core in the radial direction, and outside, close to the outer surface of the bushing, along its axis.

[0003] Field-grading layers of the condenser core are usually made of metal foil. Bushings using such field-grading layers are known, e.g. from the following patent descriptions: US 3875327, US 4 362 897, US 4 338 487, US 4 387 266, US 4 500 745 and GB 1 125 964.

[0004] Field-grading layers made of metal foil are characterized by very low surface resistivity, typically 1-3mΩ per square. The geometrical arrangement of the field-grading layers of such low resistivity in the condenser core constitutes a number of interconnected capacitance and inductance elements prone to resonant high-frequency oscillations of large quality factor. Such oscillations are triggered by electric impulses of high frequency and lead to local occurrence of high electric field in the condenser core, with a risk of insulation damage.

[0005] One of the methods to avoid such oscillations is application of field-grading layers of increased surface resistivity. Increased resistivity of the field-grading layers leads to reducing the quality factor of the oscillation circuits. In consequence, the amplitude of the oscillations is reduced and there is less risk of insulation damage. Numerous ways are known of manufacturing field-grading layers of increased electric resistivity.

[0006] From a Japanese patent description JP 01283716 there is known a cast bushing in which the field-grading layers are made of fabric or nonwoven cloth having a conductive layer on its surface, e.g. in form of conductive paint. Typical resistivity of conductive paints is much larger than that of metal.

[0007] Field-grading layers used in a bushing known from patent description W02006/001724 are made on the basis of paper, fabric or nonwoven cloth and contain conducting particles suspended in it and forming a percolating network, electrically conducting in the layer plane. The particles can be e.g. carbon nanotubes, carbon nanofibers, metallic microfibers. Such percolative structures are also characterized by electric resistivity higher than that of metals.

[0008] Another way of increasing the resistivity of the field-grading layers is using a very thin layer of metal, for example deposited on insulating material. From the un-

published patent application EP06460047 there is known an insulating structure with field-grading layers, applicable in high-voltage bushings, in which the field-grading layers are made in form of an insulating substrate layer coated with a very thin metal layer.

[0009] The innermost field-grading layer of the condenser core of a bushing is electrically connected to the conductor of the bushing. The outermost, and/or one of the other outer field-grading layers are electrically connected to the ground potential. Connection to the ground potential goes typically via the metallic flange which serves to mechanically fix the bushing to the grounded equipment.

[0010] In most of the condenser bushing types, at least one of the connections of the outer field-grading layers is arranged in a socket, so that it can be disconnected from the grounded flange and connected to a testing device to perform electrical tests on the bushing. During normal operation, the socket is short circuited by a conductive plug. Depending on the function, the socket is known as test- or measurement tap (when connected to the outermost field-grading layer) or voltage- or potential tap (when connected one of the other outer field-grading layers).

[0011] During normal operation, the connections of the inner- and the outer field-grading layers carry a relatively small capacitive current flowing through the electric capacitance of the condenser core. In surge conditions caused by a lightning impulse, operation of a surge arrester or switching, a pulse of substantially higher current is carried by the connection. A similar situation occurs during impulse testing of a bushing performed in laboratory conditions. During the pulse, the current is being distributed from the connection into the field-grading layer plane and the highest density of the surface current in the field-grading layer occurs close to the point at which the electrical connection is attached to the layer. For a circular connection point, the current density is equal to the total current divided by the circumference of the connection spot. For a typical connection used with field grading layers made of metal foil, this circumference is very small. For example, for a soldering connection, the circumference of the contact point (a drop of solder) is typically of the order of 5-15mm, and the local surface current density in the layer can be very large, much larger than the current densities in all the other layers, to which the connections are not provided. Field-grading layers of increased surface resistivity have smaller ability to conduct large electric current than the conventionally used metal foils. Thus, the application of the field-grading layers of increased resistivity, as the layers to which the connections are attached requires a dedicated, new solution.

[0012] A bushing with field-grading layers made of material of limited current carrying capacity, and, in the same time, with improved current withstand of the connection during a surge, is known from a patent description GB 539 587. The bushing comprises an additional surge-

draining layer, to which the external connection is applied, made of a stout conducting material of a high current carrying capacity. The surge-draining layer is electrically connected to the outermost field-grading layer by one or more conductive connections. During normal operation, the capacitive current flows through the conductive connection. In a surge condition, a part of the high frequency current takes the other path distributed over the whole or the major part of the surface of the field-grading layer and the impedance of that path is such that the substantial part of the high-frequency current takes this distributed path.

[0013] In that technical solution, in a surge condition, the distributed path of the current is formed by the substantial capacitance between the field-grading layer and the surge-draining layer. The resistance of the surge-draining layer is very low, compared to the impedance related to that capacitance. Effectively, during the surge, the current path goes from the connection, along the surface of the surge-draining layer and farther, through the capacitance into the field-grading layer in the direction perpendicular to both layers. Thus, virtually no current flows along the surface of the field-grading layer and even when the layer of increased resistivity is applied, there is no effect of damping of high-frequency oscillations by the resistance of that layer.

[0014] The problem to be solved is to provide an electric connection to a field grading layer of increased resistivity, made in such a way that a substantial part of the high-frequency surge current flows along the surface of that field-grading layer, thus giving the effect of damping the high-frequency oscillations but in the same time the surface current density in that layer is limited so that the layer is not damaged during the surge.

[0015] The essence of the high-voltage bushing according to the invention, comprising a condenser core and electrically conducting field-grading layers which are arranged coaxially around the central conductor and are embedded in the insulating material of the condenser core, while an electric connection is provided, by means of a current-collecting member, to at least one of the field-grading layers, and this layer is made in form of a thin metal layer deposited on an electrically insulating substrate layer or in form of a percolating network of conducting particles suspended in a layer of electrically insulating material is that the current-collecting member is located on the surface of the layer to which the electric connection is provided and covers a part of the area of that layer. The surface resistivity of the current-collecting member is many times smaller than the surface resistivity of the layer to which the electric connection is provided. The current-collecting member is shaped so that the length of the contour line of its circumference is greater than the length of the shorter side of the layer on the surface of which the current-collecting member is located.

[0016] Preferably, the length of the contour line of the circumference of the current-collecting member is select-

ed so that during the impulse test required for the bushing, the root-mean-square average of the surface density of the current flowing across the surface of the layer on which the current-collecting member is located, close to the contour line of the circumference of the current-collecting member, is smaller than the root-mean-square average of the withstand current density for that layer exposed to a pulse of a shape and duration similar to the shape and duration of the current flowing through the electric connection which drains the current during the impulse test of the bushing.

[0017] Preferably, the layer on whose surface the current-collecting member is located has surface resistivity greater than 100mΩ per square.

[0018] Preferably, the current-collecting member has an elongated shape, and it is located on the surface of the field grading layer longitudinally with respect to the direction of the longitudinal axis of the bushing.

[0019] Preferably, the current collecting member is positioned close to the symmetry axis of the field-grading layer.

[0020] Alternatively, the current-collecting member has an elongated shape, and it is located on the surface of the field grading layer perpendicularly with respect to the direction of the longitudinal axis of the bushing.

[0021] Preferably, the current-collecting member has a shape similar to a geometric figure consisting of many elongated conducting elements located parallel to one another and connected crosswise by means of another elongated conducting element.

[0022] Preferably, the current collecting member is made of metal foil.

[0023] Alternatively, the current collecting member is made of a braid or a woven or unwoven fabric containing metal wires, fibers or metal foil strips.

[0024] Preferably, the current collecting member is electrically connected with the field grading layer using electrically conducting adhesive or electrically conductive paint.

[0025] A high-voltage instrument transformer comprising a bushing according to the invention.

[0026] The bushing according to the invention is highly resistant to high-frequency voltage oscillations or impulses since the high frequency oscillations are damped by the electric resistance of the field-grading layer to which the connection is provided. In the same time, the current density in the field grading layer is limited so that the bushing is not prone to failures due to a pulse of high current occurring during surge condition.

[0027] The invention is presented as an embodiment in the drawing where fig. 1 shows schematically the longitudinal section of the high-voltage bushing, fig. 2 - the same bushing in cross-section along the line A-A, fig. 3 - the unwound outer field-grading layer together with the current-collecting member in the first embodiment of the invention, fig. 4 - the unwound outer field-grading layer together with the current-collecting member in the second embodiment of the invention, fig. 5a - the unwound

outer field-grading layer together with the current-collecting member in the third embodiment of the invention, fig. 5b - the field-grading layer of fig. 5a with the relevant surface areas indicated, fig. 6 - an example of the waveform of the current flowing through the connection of the field-grading layer during the impulse test, and fig. 7 - the outer field-grading layers, in cross-section along the line A-A, in the first embodiment of the invention with the distribution of the current from the connection to the field-grading layers indicated in the drawing.

[0028] The high-voltage bushing according to the invention comprises a condenser core 1 which is arranged around a central cylindrical conductor 2. The condenser core 1 is placed inside a standard insulating casing intended for high-voltage bushings, which is not shown in the drawing. The condenser core 1 is comprised of many field-grading layers 3 which are placed cylindrically, coaxially around the central cylindrical conductor 2 and are embedded in insulating material 4 of the condenser core 1. To one of the layers 3, for example the outermost layer 3a, there is connected, by means of a current-collecting member 5, an external electric connection 6 which connects the layer 3a with an external conducting flange 7 by means of which the bushing is fixed to the earthed wall of the electric equipment, not shown in the drawing. The electric connection 6 can be also connected to one of the other layers 3, typically layers located nearer the flange 7, which is not shown in the drawing. The connection 6 can also be connected to the layer 3 located closest to the central conductor 2, and the connection 6 is then connected to the central conductor 2, which is not shown in the drawing either. The connection 6 connected to one of the layers 3 located nearer the flange 7 or to the outer layer 3a can be also connected to a test- or voltage tap in form of the contact of a socket located in the flange 7, which is not shown in the drawing. Such socket makes it possible to connect measuring instruments to the appropriate layer 3 or 3a, or, by short-circuiting the socket contact with the flange 7, allows the earthing of the given layer 3 or 3a. The field-grading layer 3a of the exemplary embodiment of the invention is made of paper filled with a percolating network of metallic fibres and its surface resistance is $10\Omega - 20\Omega$ per square. Alternatively, the field-grading layer 3a is made as a metallic film applied on an electrically insulating substrate layer made of insulating paper and its surface resistance is $5\Omega - 15\Omega$ per square. The current-collecting member 5 is placed on the outermost layer 3a and is in electric contact with it over the whole area of the current-collecting member 5. The current-collecting member 5 has a shape similar to a rectangle with rounded corners and in the first embodiment of the invention it is located on the layer 3a in such way that the longer sides of the rectangle are located parallel to the direction of the longitudinal axis of the bushing, marked by an arrow 8 in the drawing. The current-collecting member 5 is located near the axis of symmetry of the layer 3a. The current-collecting member 5 is made as a flat braid consisting of copper wires, whose

surface resistance is at least 1000 times less than the surface resistance of the field-grading layer 3a. The contour line of the circumference "L" of the current-collecting member 5 is a line, substantially perpendicularly to which the current flow distribution takes place in plane of the layer 3a from the member 5 to the layer 3a. The current is supplied to the current-collecting member 5 through the connection 6. The length of the contour line of the circumference "L" is approximately twice longer than the length of the shorter side of the layer 3a.

[0029] In the second embodiment of the invention, the current-collecting member 5, which is located on the outermost layer 3a, has a shape similar to a rectangle with rounded corners and it is located on the layer 3a in such way that the longer sides of the rectangle are located perpendicularly to the direction of the longitudinal axis of the bushing, marked by a bi-directional arrow 8 in the drawing. The current-collecting member 5 is made as a flat braid, consisting of copper wires, whose surface resistance is at least 1000 times less than the surface resistance of the field-grading layer 3a. The contour line of the circumference "L" of the current-collecting member is a line, substantially perpendicularly to which the current flow distribution takes place in plane of the layer 3a from the current-collecting member 5 to the layer 3a. The current is supplied to the member 5 through the connection 6. The length of the contour line of the circumference "L" is approximately 4 times longer than the length of the shorter side of the layer 3a.

[0030] In the third embodiment of the invention, the current-collecting member 5, which is located on the outermost layer 3a has a shape similar to a geometric figure comprised of many elongated, preferably rectangular conducting elements 9 with rounded corners, located parallel to one another and interconnected crosswise by means of another rectangular conducting element 10 with rounded corners, whose longer sides are located perpendicularly to the direction of the longitudinal axis of the bushing, marked with a bi-directional arrow 8 in the drawing. The conducting elements 9 and 10 are made as a flat braid of copper wires, whose surface resistance is at least 1000 times less than the surface resistance of the field-grading layer 3a. The contour line of the circumference "L" of the current-collecting electrode is a line, substantially perpendicularly to which the current flow distribution takes place in plane of the layer 3a from the current-collecting member 5 to the layer 3a. Current is supplied to the conducting element 10 of the current-collecting member 5 through the connection 6. The length of the contour line of the circumference "L" is approximately 10 times longer than the length of the shorter side of the layer 3a.

[0031] In all the embodiments, the length of the contour line "L" of the circumference of the current-collecting member 5 is so selected that during the impulse test required for the bushing, the root-mean-square average of the surface density of the current flowing across the surface of the layer 3a near the contour line "L" is smaller

than the root-mean-square average of the withstand current density for the layer 3a exposed to a pulse of a form and duration similar to the form and duration of current flowing through the connection 6 during the impulse test of the bushing.

[0032] In the embodiment, the bushing undergoes a chopped lightning impulse test. An exemplary waveform of the surge current I_{CLI} flowing through the connection 6 during such test is shown in fig. 6.

[0033] As shown in fig. 7, the surge current I_{CLI} runs through the connection 6 to the current-collecting member 5. From there, a part I_{CC} of the surge current I_{CLI} , flows to the layer 3a in the direction perpendicular to its surface and farther, capacitively to the other field-grading layers 3. The other part of the surge current, I_{NC} , flows into the part of layer 3a not covered by the current-collecting member 5 in the direction parallel to its surface and substantially perpendicular to the contour line "L" (fig.3) of the circumference of the current-collecting member 5. This part of the surge current flows farther from the layer 3a capacitively to the successive field-grading layers 3 as well. Therefore, since the capacitive impedance is the main part of the high-frequency impedance of the circuit, the ratio of the values of the currents I_{CC} and I_{NC} corresponds to the ratio of the respective capacitances, which in turn are proportional to the surface area S_{CC} of the current-collecting member 5 and the surface area S_{NC} of the layer 3a not covered by the current-collecting member 5, respectively, with the exception of the surface area of the zone 11 on which fragments of the wound layer 3a overlap. Hence the other part of the surge current is:

$$I_{NC} = I_{CLI} \frac{S_{NC}}{S_{3a}},$$

where S_{3a} is the surface area of the layer 3a except for the surface area of the zone 11 on which fragments of the rolled up layer 3a overlap.

[0034] The surface density ρ_L of the current flowing across the surface of the layer 3a, near the contour line "L", is, on average, I_{NC}/L , where L is the length of the contour line "L", hence

$$\rho_L = \frac{I_{CLI} \cdot S_{NC}}{L \cdot S_{3a}}.$$

[0035] Using the above equation, the length L is selected so that the root-mean-square average current density ρ_L does not exceed the average withstand current density for the material of which the layer 3a embedded in insulating material used in the bushing is made. The root-mean-square average withstand current density for

the material of the layer 3a is defined for a pulse of a form similar to the form of the pulse I_{CLI} , or the form of its envelope indicated by a dashed line, both indicated in fig. 6 and of duration identical with or longer than the duration of the pulse I_{CLI} .

[0036] For such selection of the contour line L length, the material of the layer 3a is not damaged during the applied impulse test. At the same time, a large part I_{NC} of surge current I_{CLI} flows across the surface of the layer 3a and the electric resistance of this surface contributes to the attenuation of the high-frequency oscillations.

[0037] The above described division of the surge current I_{CLI} into the currents I_{CC} and I_{NC} applies to a case where the connection 6 is provided to the outer field-grading layer 3a. For a case where the connection 6 is provided to another layer, the division of the surge current takes place according to the relation between other corresponding surfaces. In particular, for the innermost layer closest to the central conductor 2, the division of currents takes place in proportion to the corresponding surface areas of the next, neighbouring it on the outside, field-grading layer.

[0038] In all embodiments of the invention, the current-collecting member 5 or its elements 9 and 10 can be alternatively made of metallic foil which is located on the surface of the layer 3a.

[0039] In all embodiments of the invention, the current-collecting member 5 or its elements 9 and 10 can be alternatively made as a braid, or a woven or unwoven fabric containing metal wires, fibres or metal foil strips.

[0040] In all embodiments of the invention, the current-collecting member 5 can be alternatively electrically connected with the field-grading layer 3a by means of a layer of conductive adhesive and/or paint, which is not shown in the drawing.

[0041] Alternatively, the bushing according to the invention is an element of a high-voltage instrument transformer.

Claims

1. A high-voltage bushing comprising a condenser core (1) and electrically conductive field-grading layers (3) which are arranged coaxially around the central conductor (2) and are embedded in insulating material (4) of the condenser core (1), while an electric connection (6) is provided to at least one layer (3a) of the field-grading layers (3) by means of a current-collecting member (5), and the layer (3a) is made in form of a thin metal layer deposited on an electrically insulating substrate layer or in form of a percolating network of conductive particles suspended in a layer of electrically insulating material, **characterised in that** the current-collecting member (5) is located on the surface of the layer (3a) and it covers a part of the surface area of the layer (3a) and it has a surface resistivity many times smaller than the surface re-

sistivity of the layer (3a) and it is shaped so that the length of the contour line of its circumference (L) is greater than the length of the shorter side of the layer (3a).

2. A bushing according to claim 1, **characterised in that** the length of the contour line of the circumference (L) of the current-collecting member (5) is selected so that during the impulse test required for the bushing, the root-mean-square average of the surface density of the current flowing across the surface of the layer (3a) close to the contour line (L) is smaller than the root-mean-square average of the withstand current density for the layer (3a) exposed to a pulse of a shape and duration similar to the shape and duration of the current flowing through the connection (6) during the impulse test of the bushing. 5 10 15
3. A bushing according to claim 1 or 2, **characterised in that** the layer (3a) has surface resistivity greater than 100mΩ per square. 20
4. A bushing according to any of the previous claims, **characterised in that** the current-collecting member (5) has an elongated shape, and it is located on the surface of the layer (3a) longitudinally with respect to the direction of the longitudinal axis of the bushing. 25
5. A bushing according to claim 4, **characterized in that** the current collecting member (5) is positioned close to the symmetry axis of the field-grading layer (3a). 30
6. A bushing according to claims 1, 2 or 3, **characterised in that** the current-collecting member (5) has an elongated shape, and it is located on the surface of the layer (3a) perpendicularly with respect to the direction of the longitudinal axis of the bushing. 35 40
7. A bushing according to claims 1, 2 or 3, **characterised in that** the current-collecting member (5) has a shape similar to a geometric figure, composed of many elongated conductive elements (9), positioned parallel to one another and connected crosswise by means of another elongated conducting element (10). 45
8. A bushing according to any of the previous claims **characterized in that** the current collecting member (5) is made of metal foil. 50
9. A bushing according to any of the claims 1 to 7, **characterized in that** the current collecting member (5) is made of a braid or a woven or unwoven fabric containing metal wires, fibers or metal foil strips. 55
10. A bushing according to any of the previous claims,

characterized in that the current collecting member (5) is electrically connected with the field grading layer (3a) using electrically conducting adhesive or electrically conductive paint.

11. A high-voltage instrument transformer, **characterized in that** it comprises a bushing according to the invention.

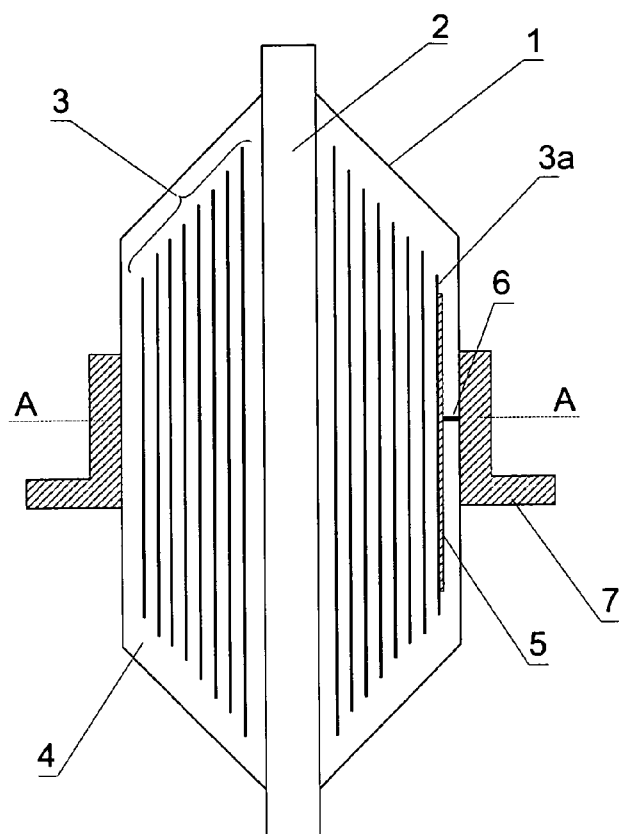


Fig. 1

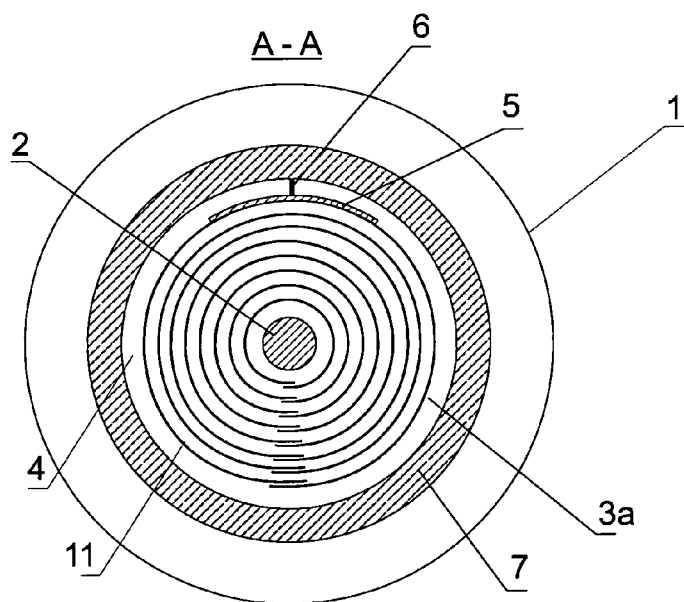


Fig. 2

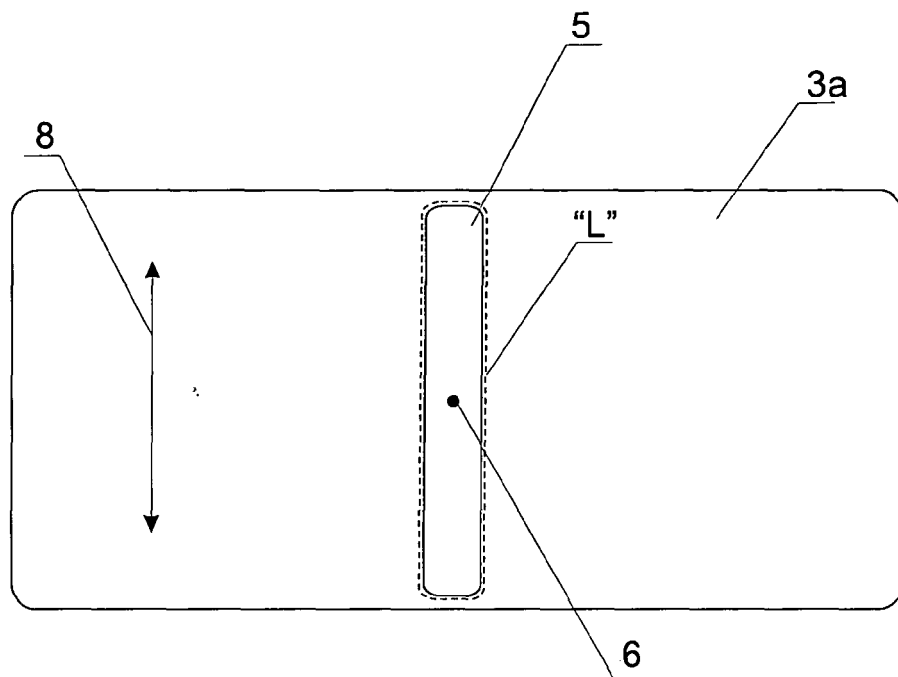


Fig. 3

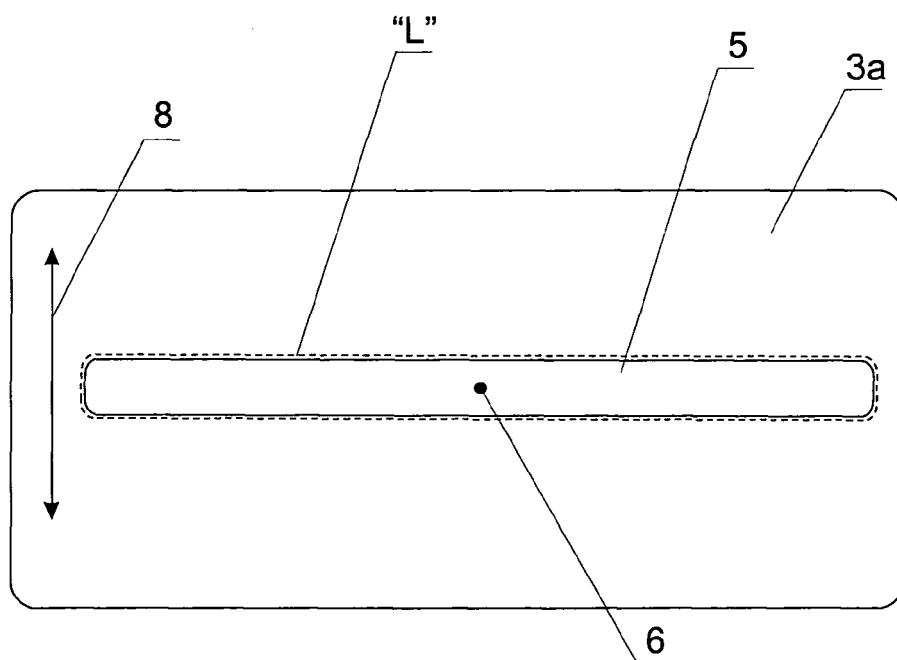


Fig. 4

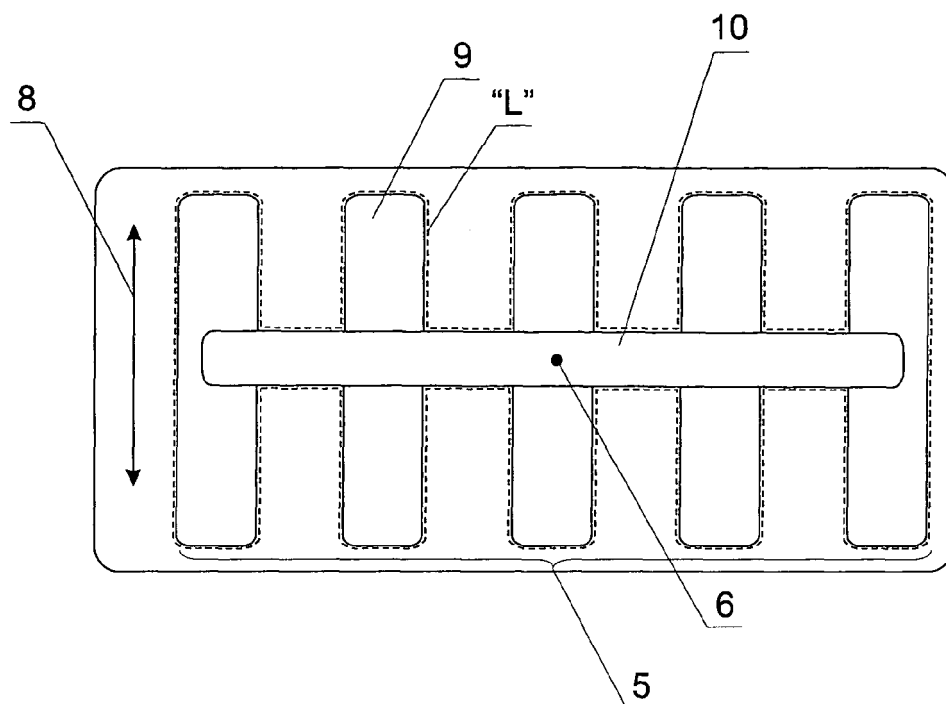


Fig. 5a

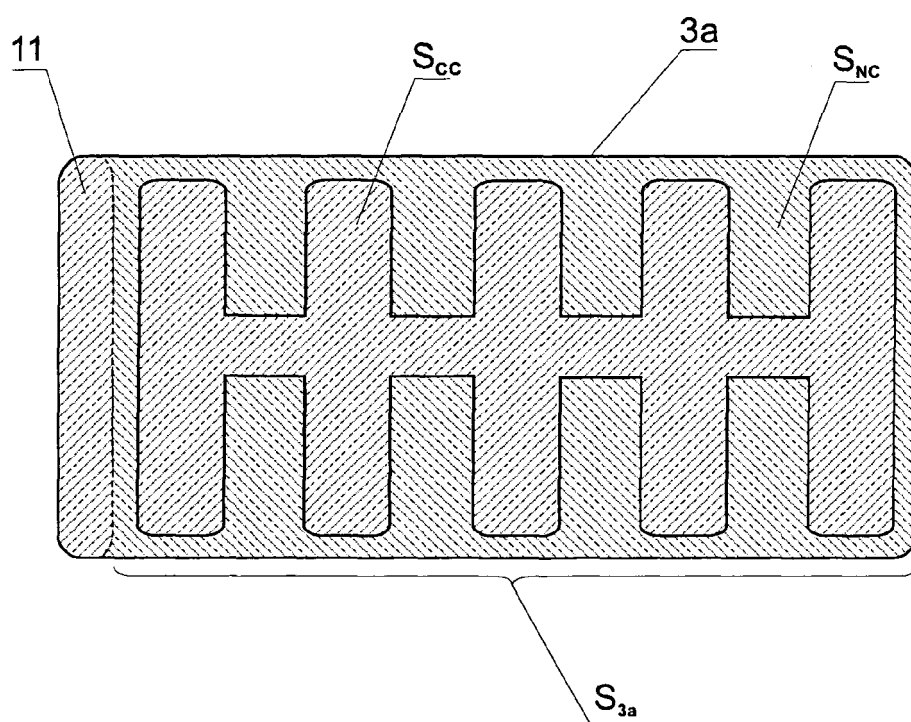


Fig. 5b

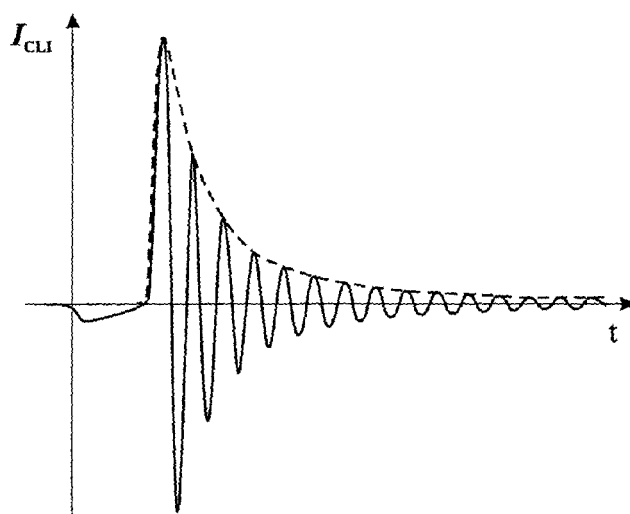


Fig. 6

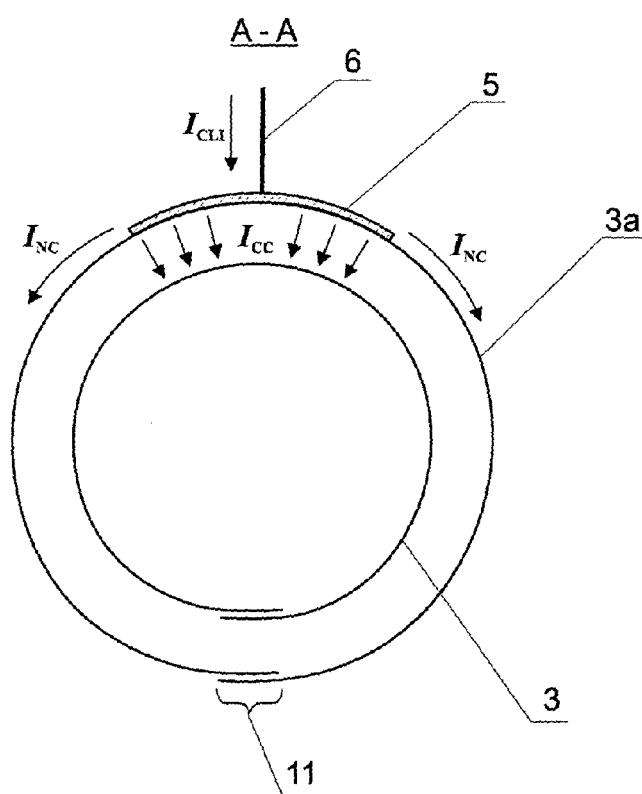


Fig. 7



EUROPEAN SEARCH REPORT

Application Number
EP 08 46 0041

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A,D	GB 539 587 A (REYROLLE A & CO LTD; IAN WARD ANDERSON KIRKWOOD) 17 September 1941 (1941-09-17) * page 1, line 34 - line 51 * * page 4, line 80 - line 12; figure 1 * -----	1,11	INV. H01B17/28
			TECHNICAL FIELDS SEARCHED (IPC) H01B
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 16 February 2009	Examiner Knack, Steffen
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P04C01)

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
GB 539587	A	17-09-1941	NONE

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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